# ESC201T : Introduction to Electronics

## Lecture 25: Amplifiers-1

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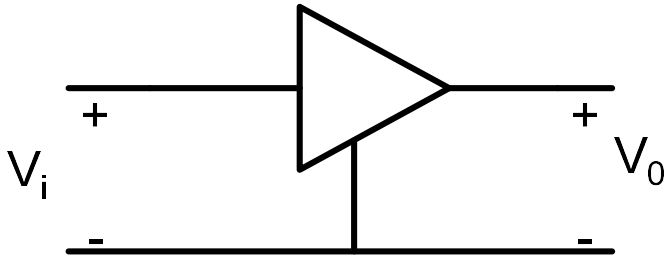
**“Amplification is the heartbeat of Electronics”**

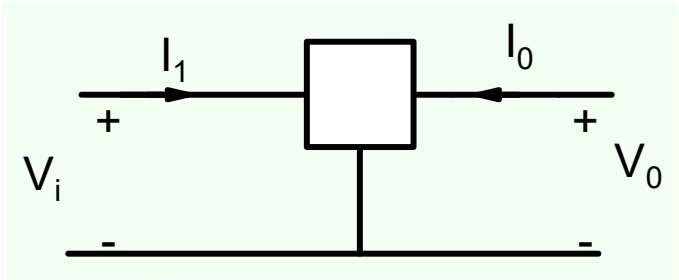
# Voltage Amplification

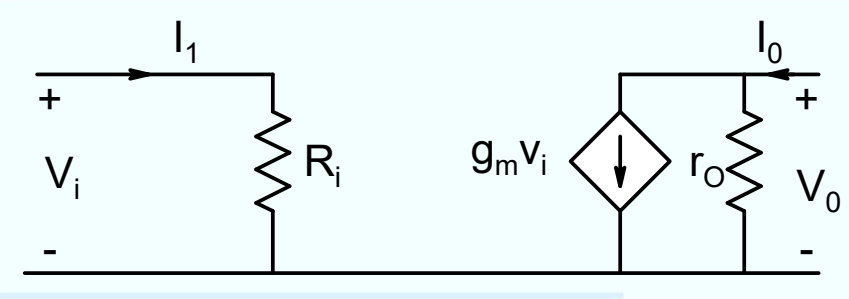



$V_o = G \times V_i$

$G > 1$ and constant

Consider a 3-terminal unilateral linear device

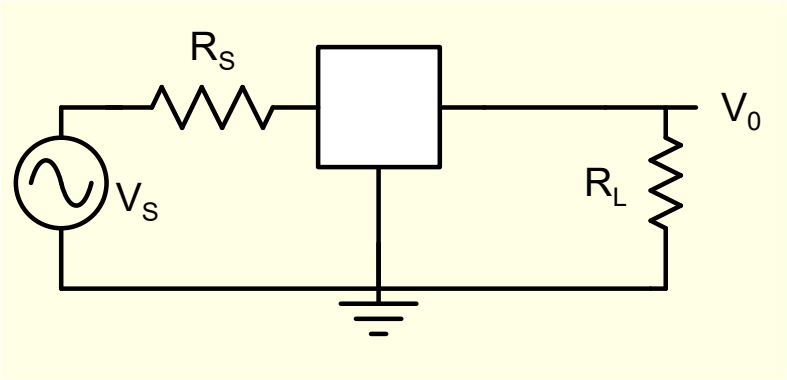


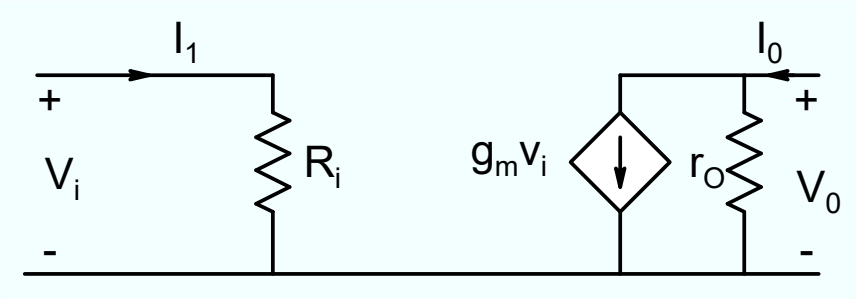



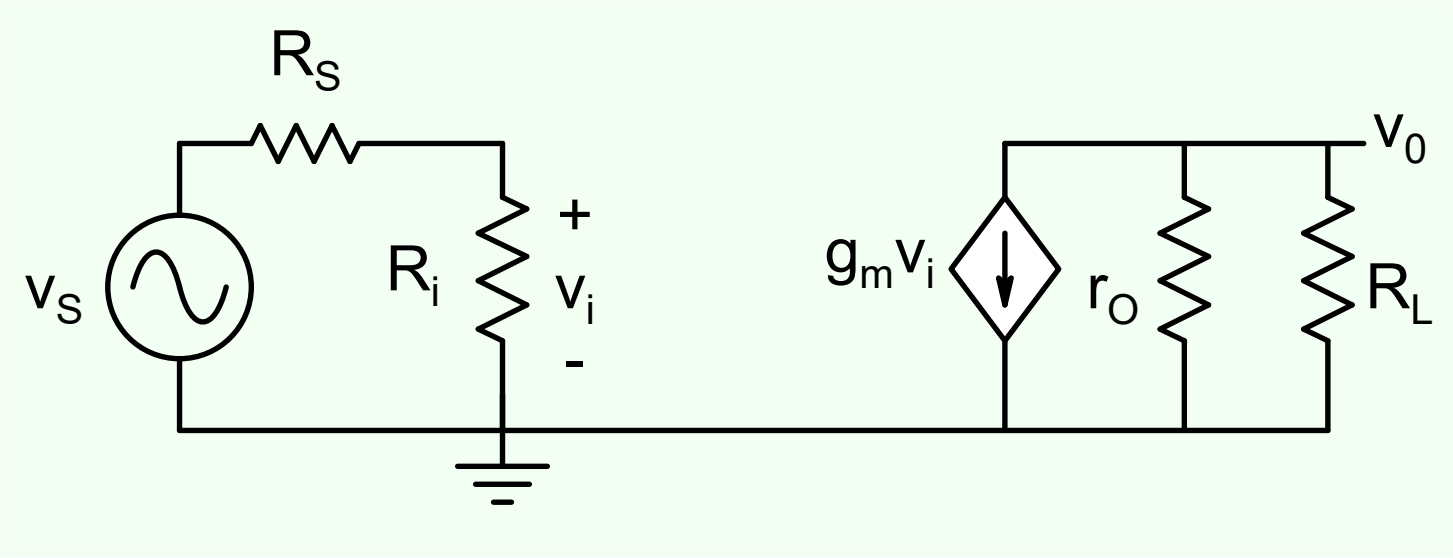

$R_i$ =input resistance= $V_i / I_i$ ; Transconductance: $g_m = \left. \frac{I_o}{V_i} \right|_{V_O=0}$

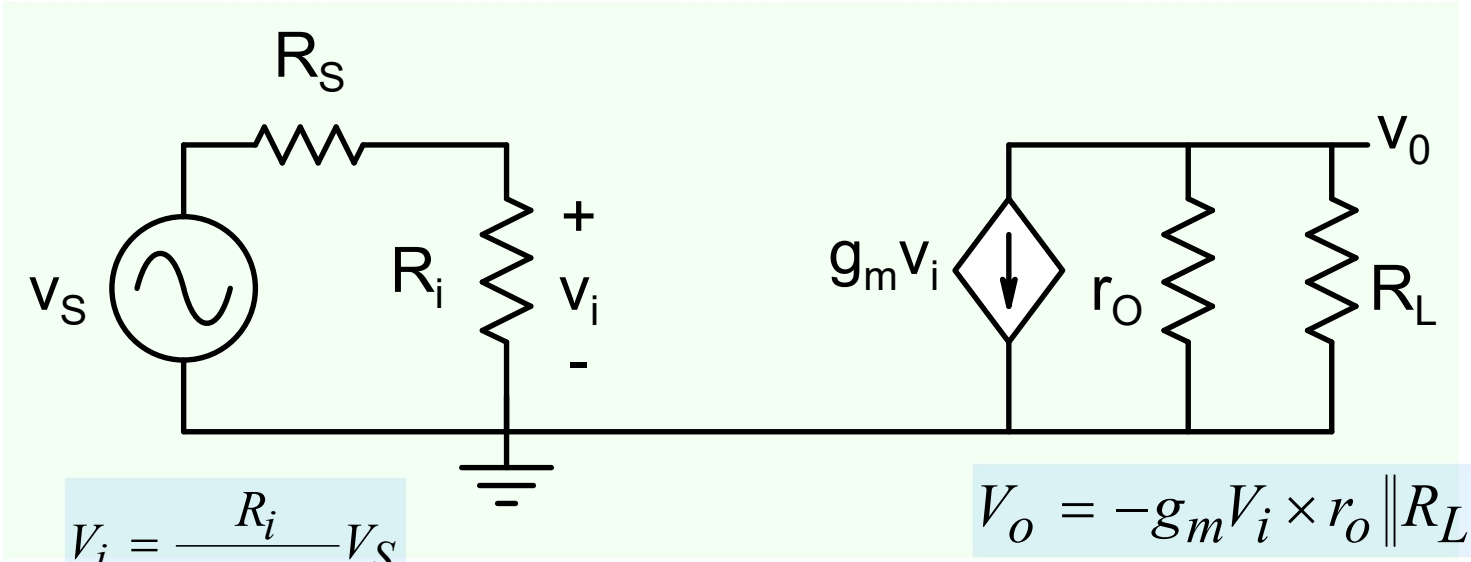
Output conductance: $g_o = 1/r_o = \frac{Io}{V_o} \Big|_{V_i=0}$

# Voltage Amplifier






$$V_i = \frac{R_i}{R_i + R_S} V_S$$

$$V_o = -g_m V_i \times r_o \| R_L$$

$$A_V = \frac{V_o}{V_s} = -g_m r_o \times \frac{R_L}{r_o + R_L} \times \frac{R_i}{R_i + R_S}$$

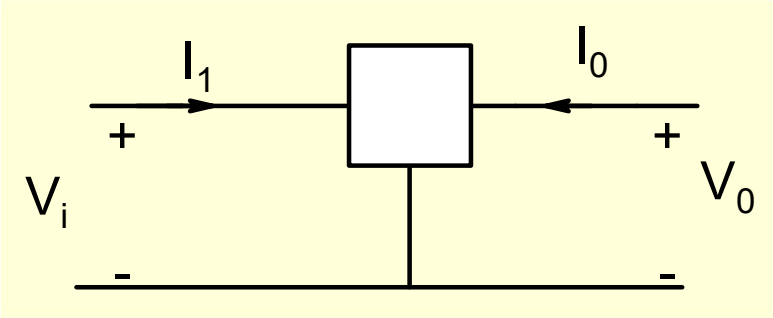
$$|A_V| \leq g_m \times r_o$$

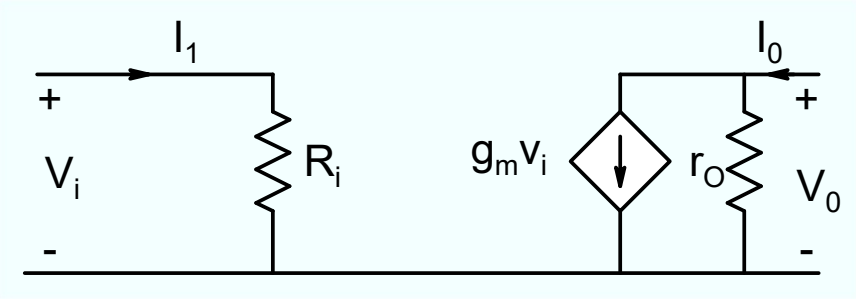
Necessary Condition for Voltage Amplification : $g_m \times r_o > 1$

## Voltage Amplification

$$g_m r_o >> 1 \qquad g_m >> g_o$$

Transconductance >> Output Conductance



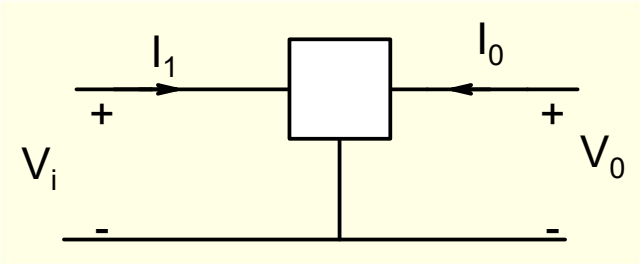



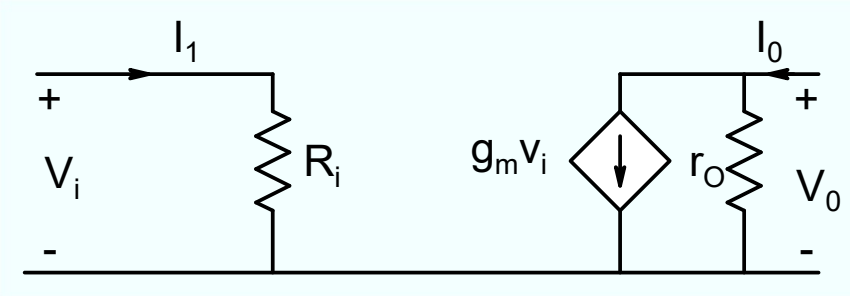

## Transistor

# Transistor

## Trans-resistor

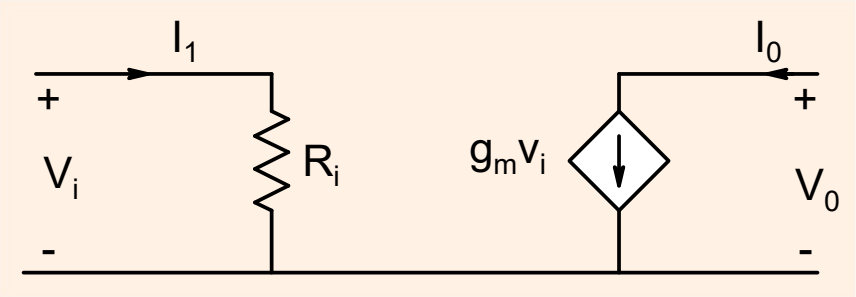

Current $I_O$ is much more sensitive to $V_{IN}$ than $V_O$




$$g_m\, r_o >> 1$$

In the ideal case $r_o$ is infinite



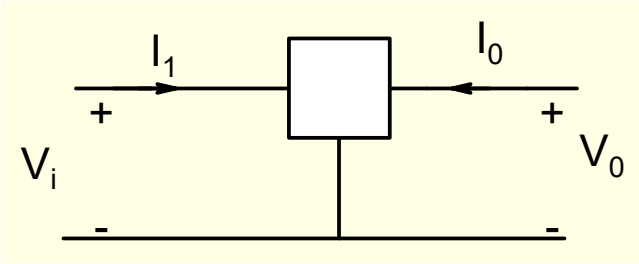

$$A_V = \frac{V_o}{V_s} = -g_m r_o \times \frac{R_L}{r_o + R_L} \times \frac{R_i}{R_i + R_S} = -g_m R_L \times \frac{R_i}{R_i + R_S}$$

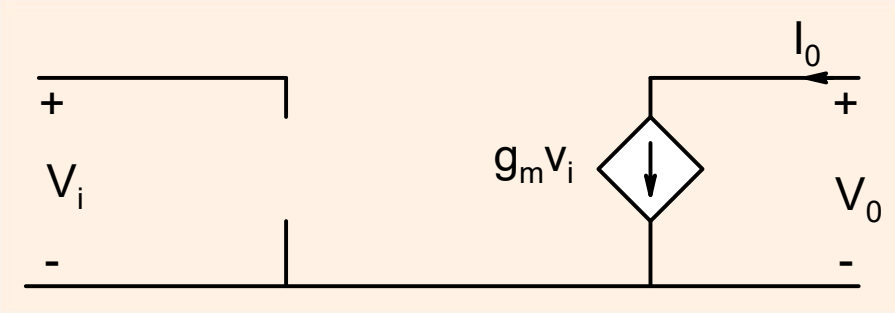
We would ideally like input resistance $R_i$ to be infinite as well !

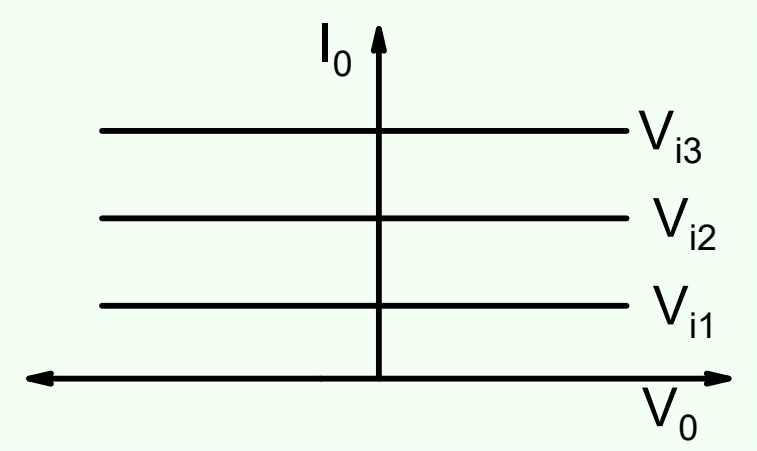
$$A_V = -g_m R_L$$

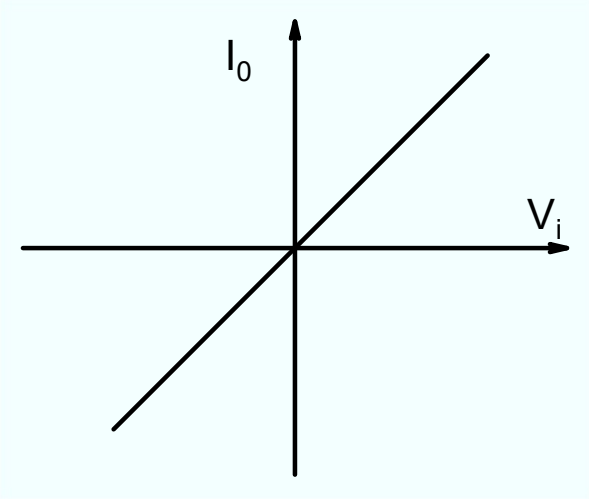
**Note that we have power gain as well which is essential for calling a device as an Amplifier**

# An ideal 3-terminal device for Voltage Amplification



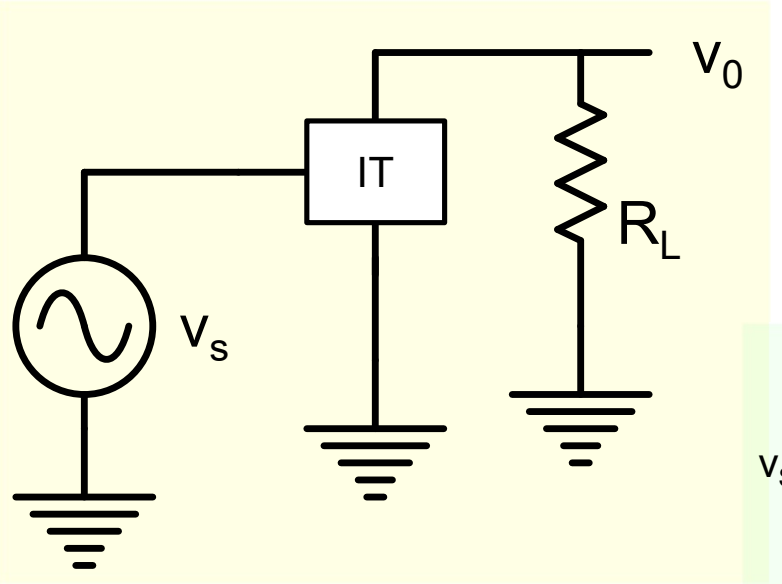



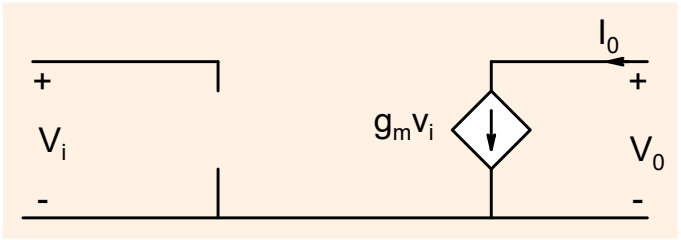



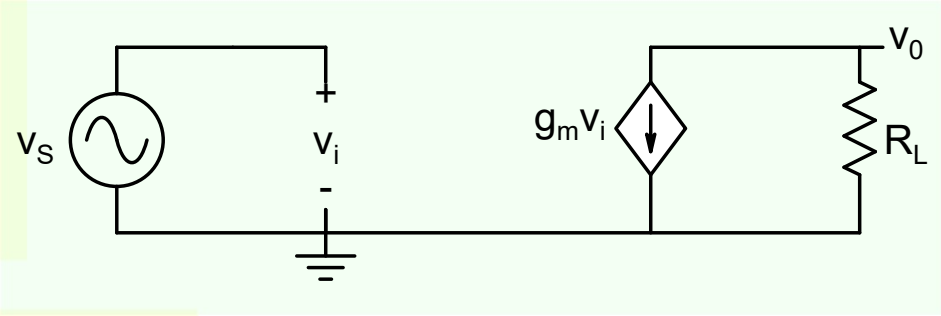

# Ideal Transistor Characteristics

# Ideal Transistor (IT)

Making a voltage amplifier with an ideal transistor is straightforward



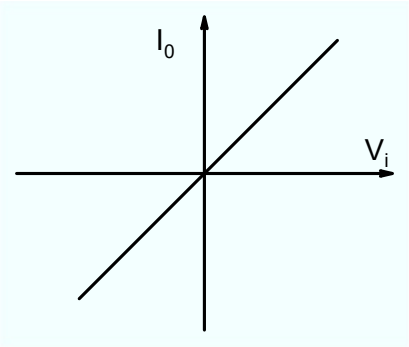



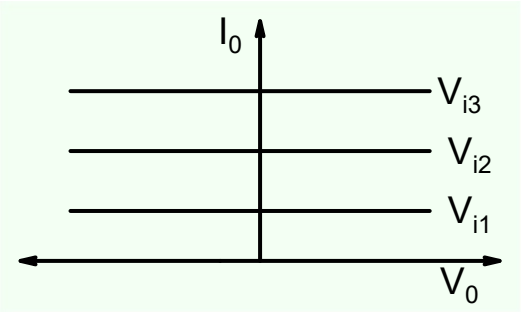




$$A_V = \frac{v_o}{v_s} = -g_m R_L$$

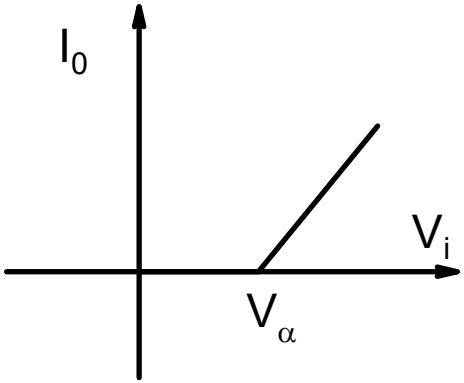
**In practice there is no element which has the characteristics of ideal transistor !**

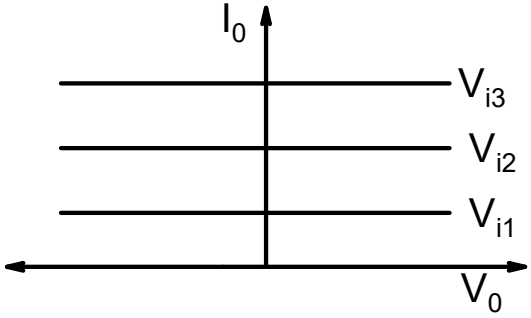
**Ideal transistor**



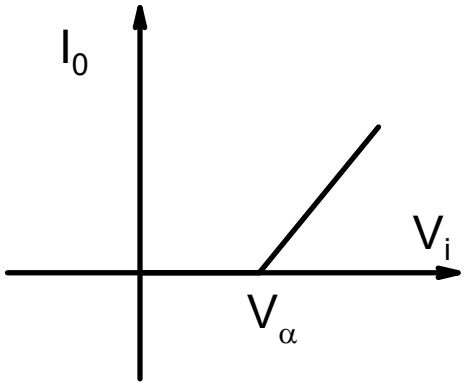



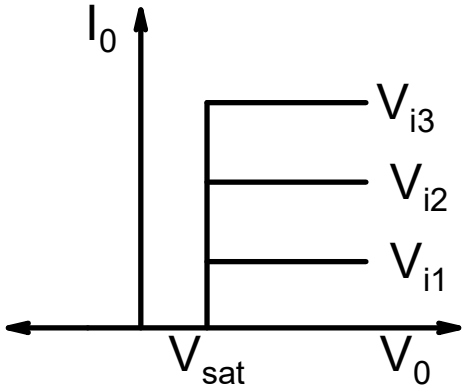

**Device X**



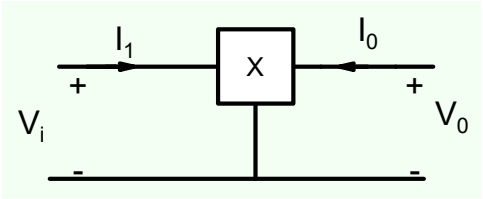

**Device Y**

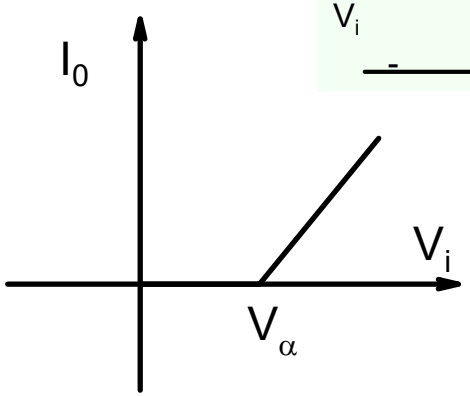


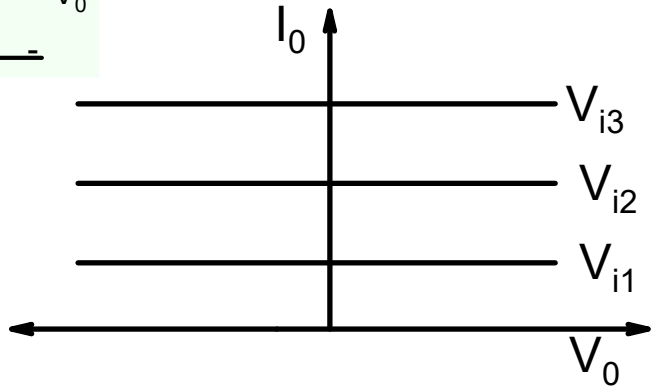




How do we use elements such as X, Y etc to make amplifiers?

## Device X

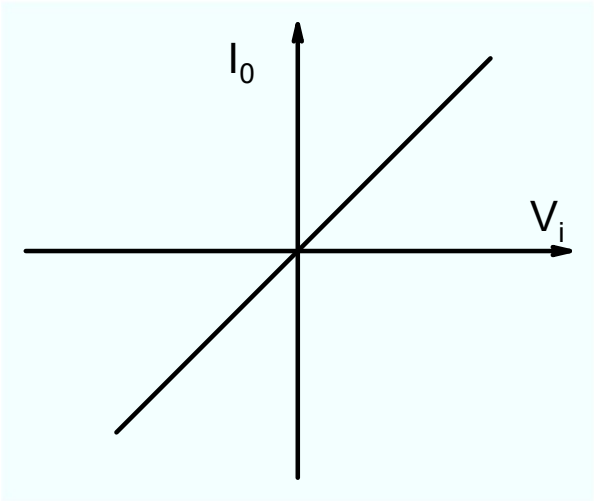


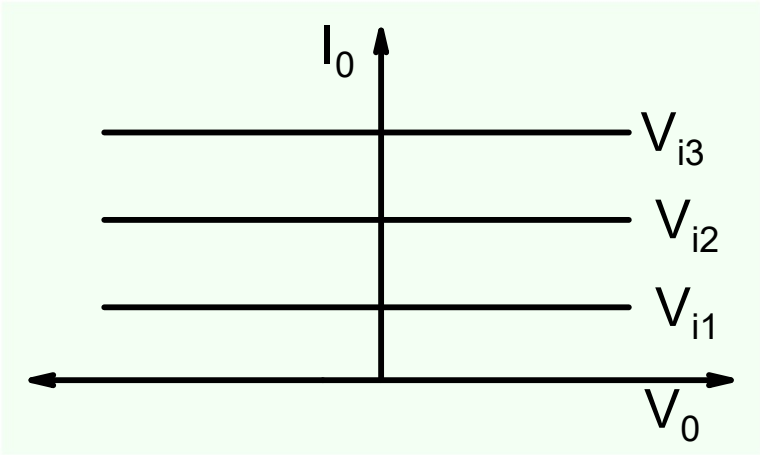



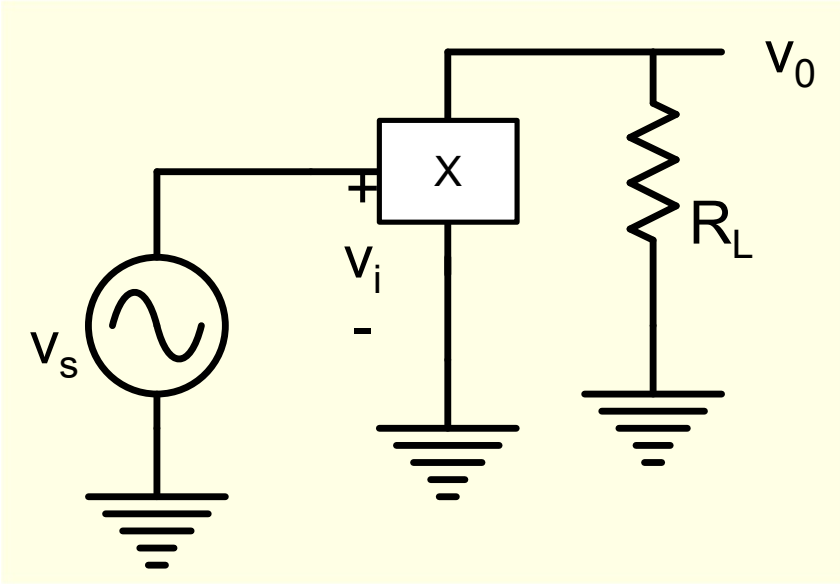

$$I_o = 0 \qquad \text{for } V_i \le V_\alpha$$
$$= g_m \times (V_i - V_\alpha) \text{ for } V_i > V_\alpha$$

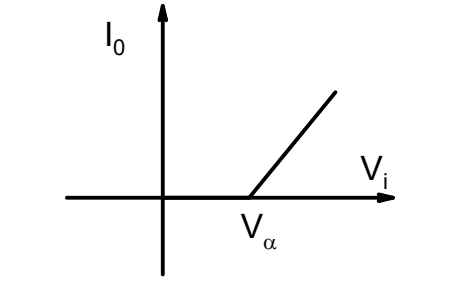
## Ideal Characteristics

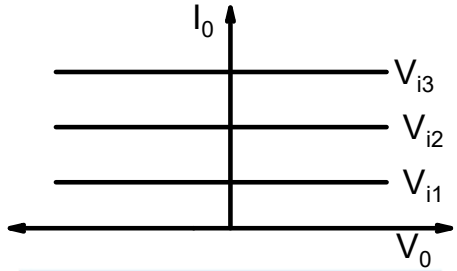


## How do we use device X to make an amplifier?

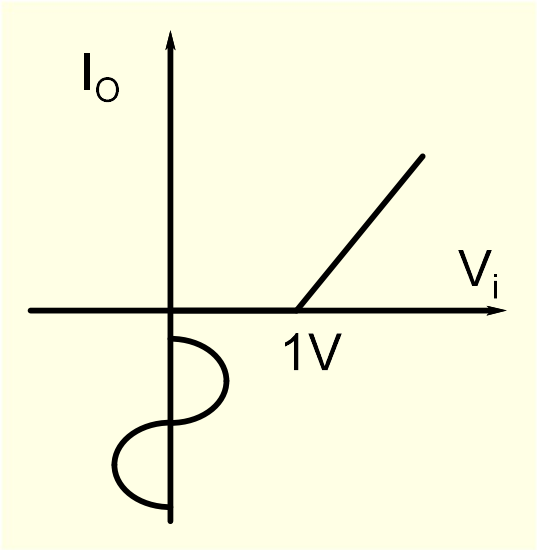



$V_\alpha = 1V; g_m = 0.01\Omega^{-1}$

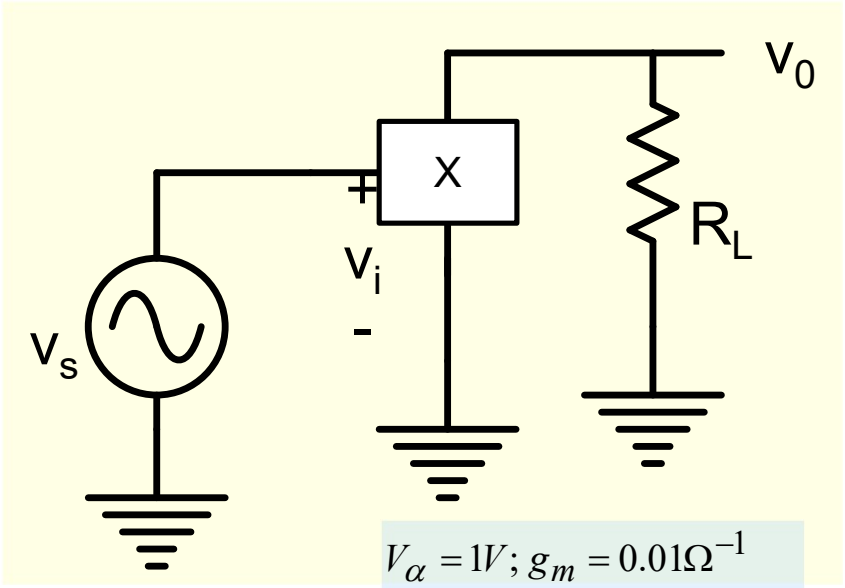
$R_L = 1K; v_s = 0.5V\ Sin\ \omega t$




$I_O = 0 \Rightarrow V_O = 0$

No Amplification

## How do we use device X to make an Amplifier?

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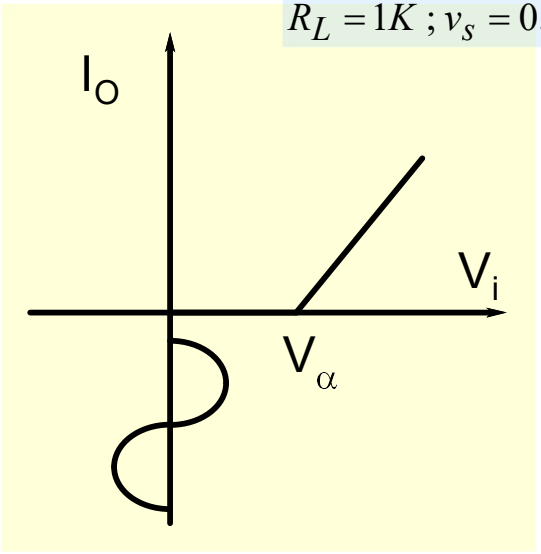
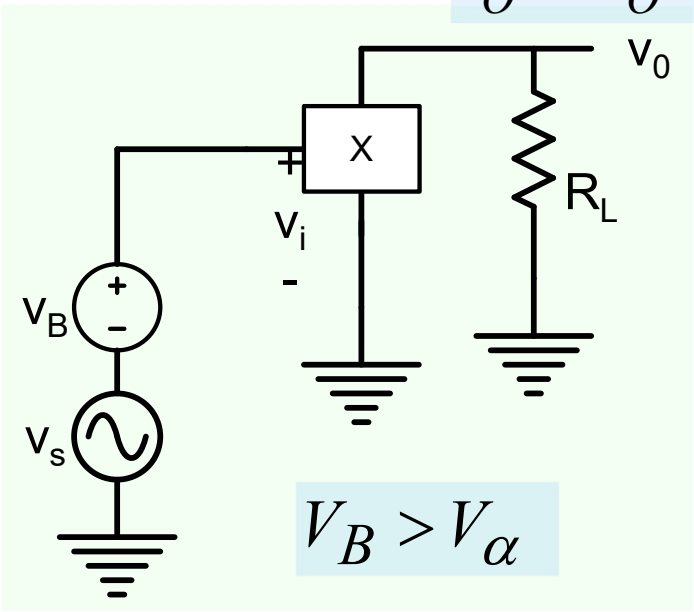
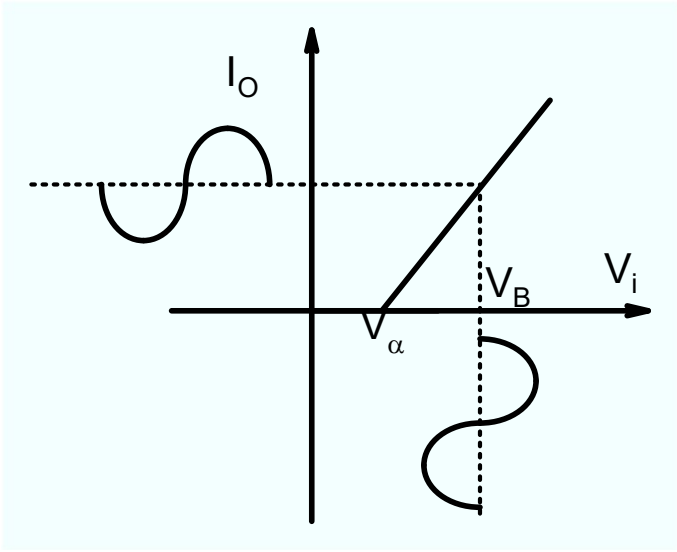


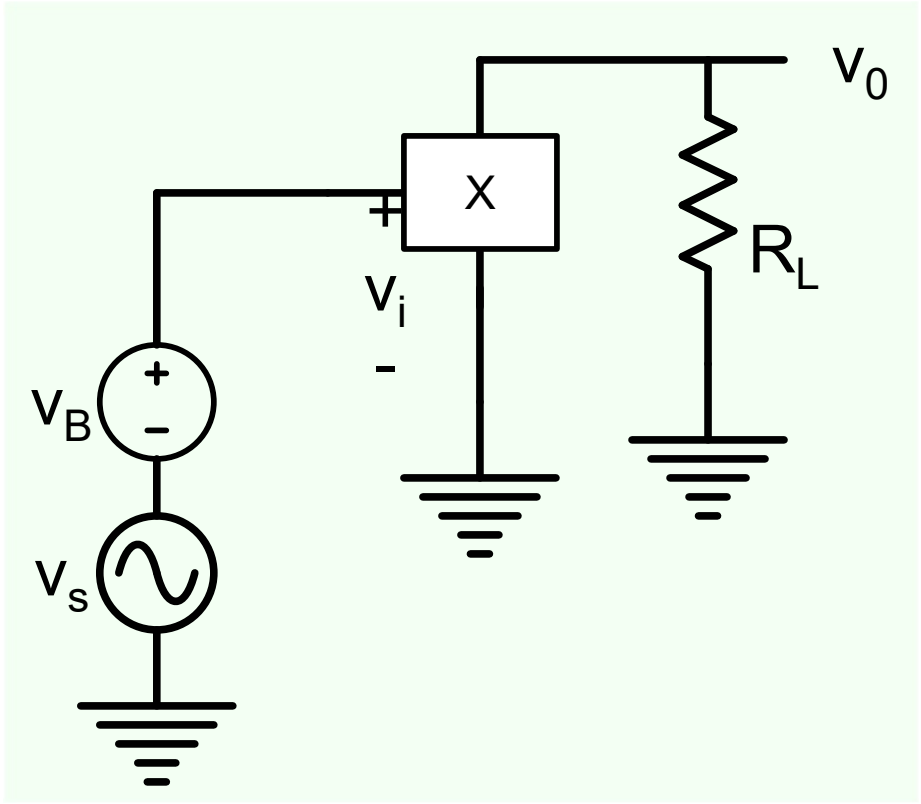

$V_O = -I_O \ R_L$

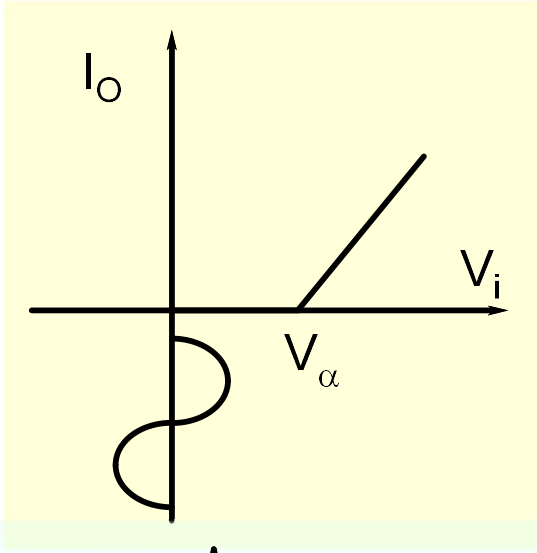


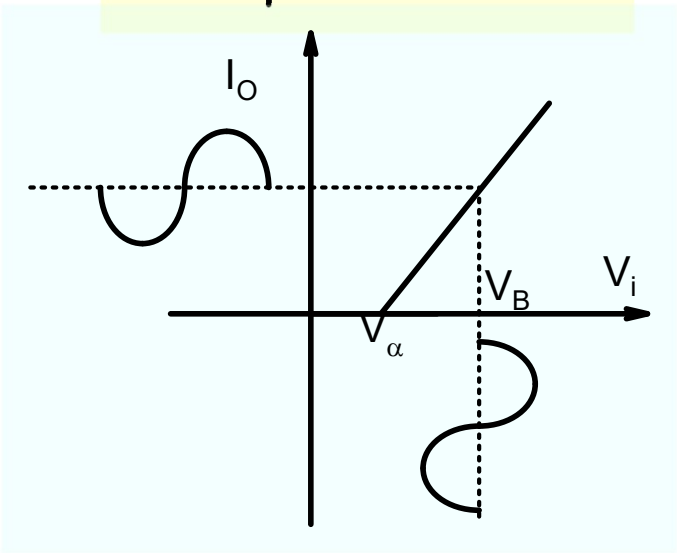

$V_B > V_\alpha$



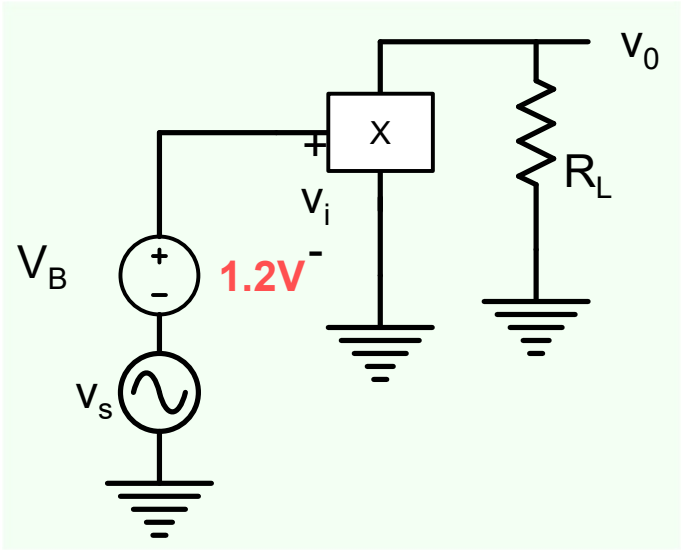
When only a part of device characteristics is suitable for amplification, then we need to push the device into that region by applying suitable bias voltages. This process is called BIASING



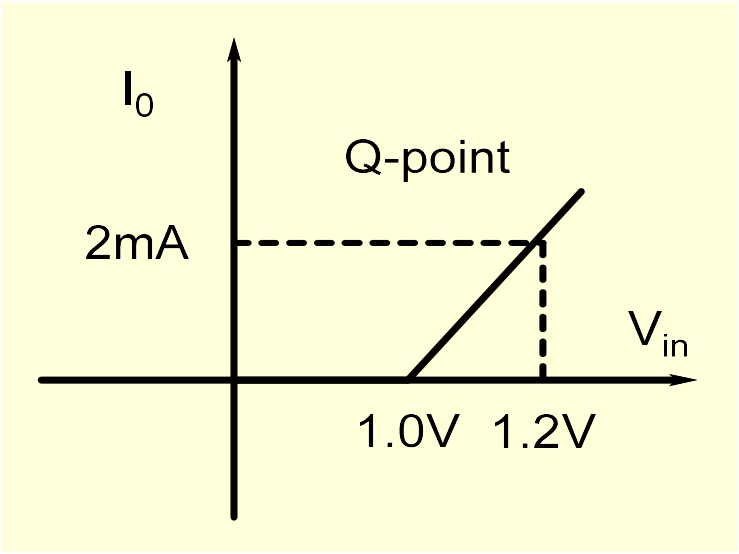



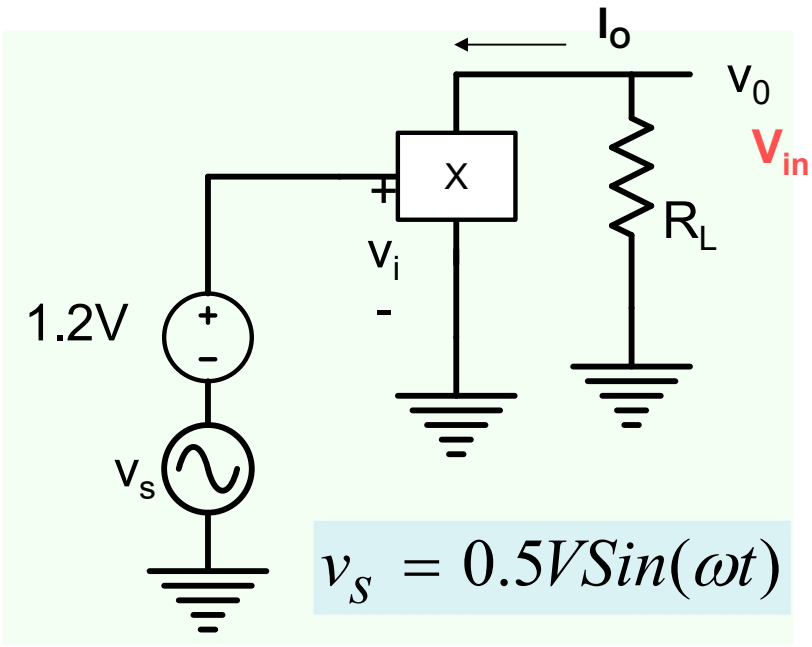
# How should one choose the bias voltage $V_B$ ?



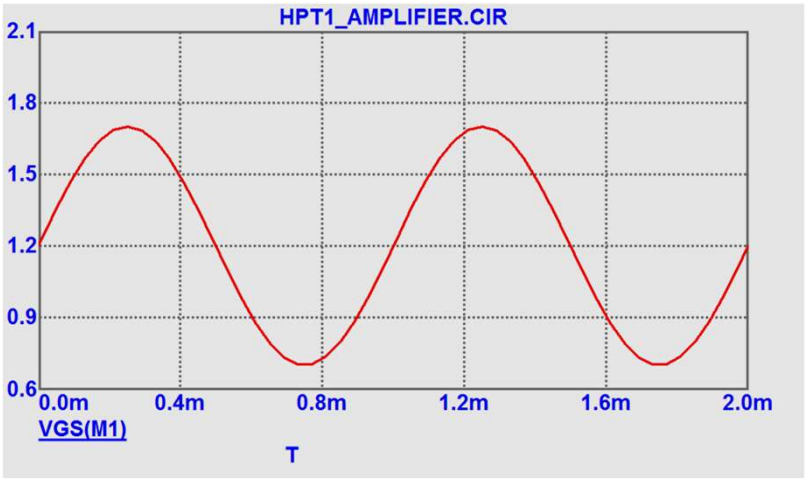

$$v_s = 0.5V \ Sin \ \omega t$$

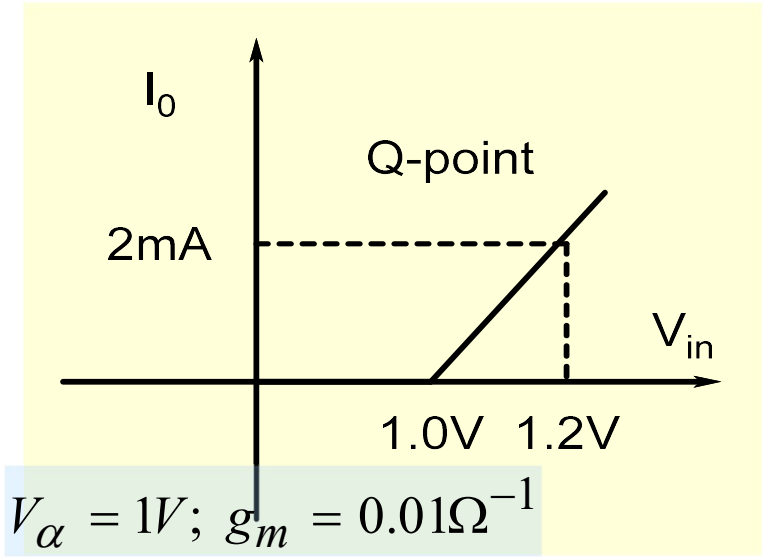



**Quiescent point or Bias point**

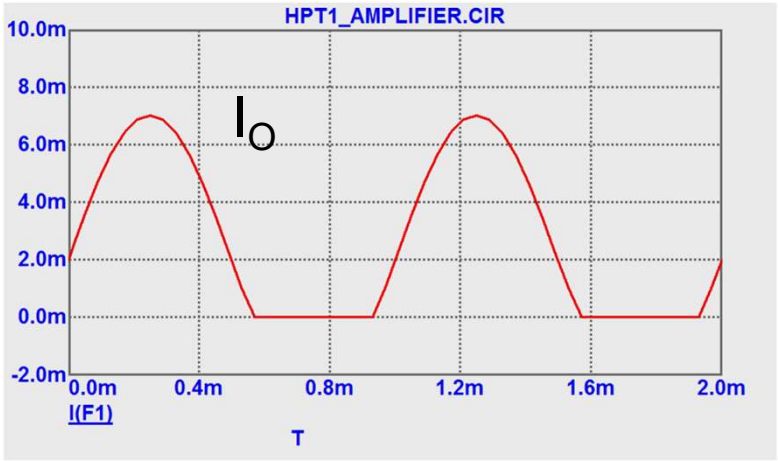



$$v_s = 0.5VSin(\omega t)$$



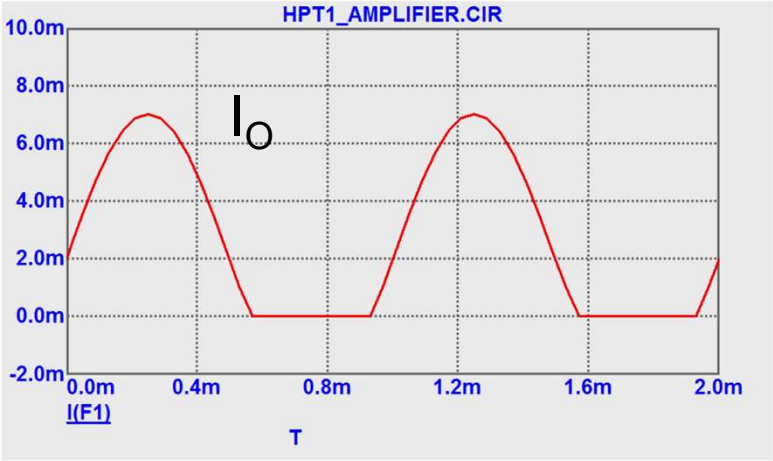



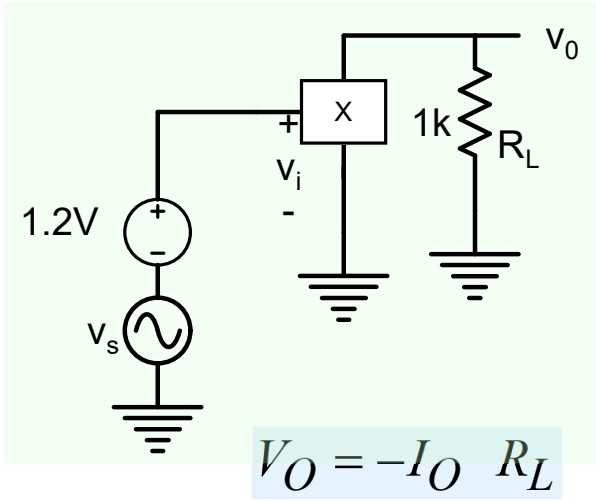

$$V_\alpha = 1V;\ g_m = 0.01\Omega^{-1}$$

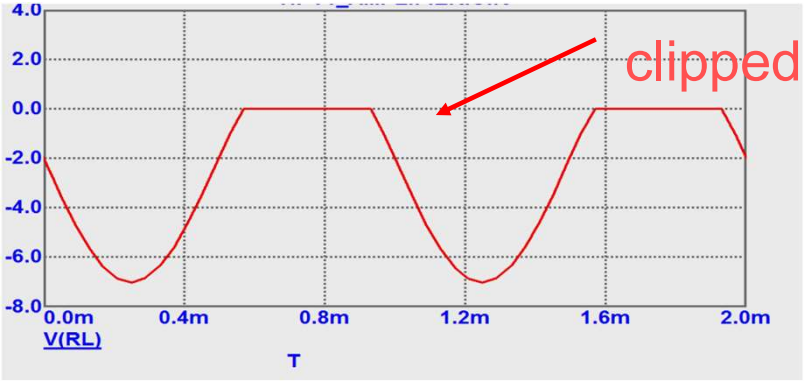



$$V_O = -I_O \ R_L$$

# Output voltage is distorted !

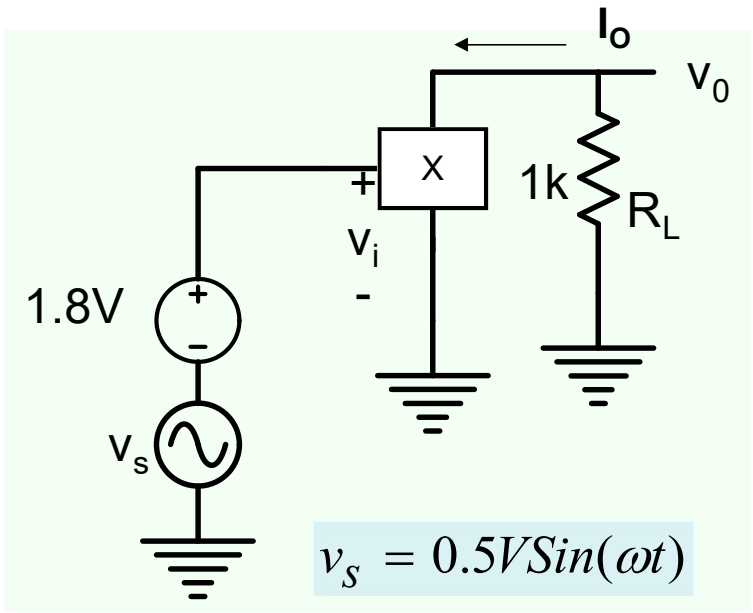


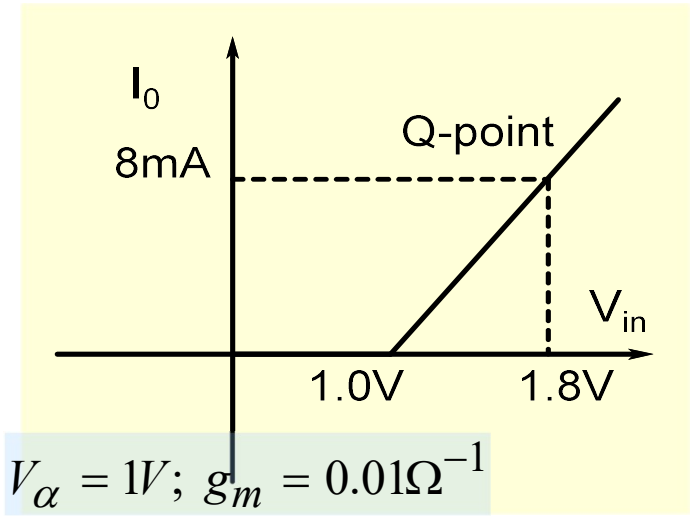



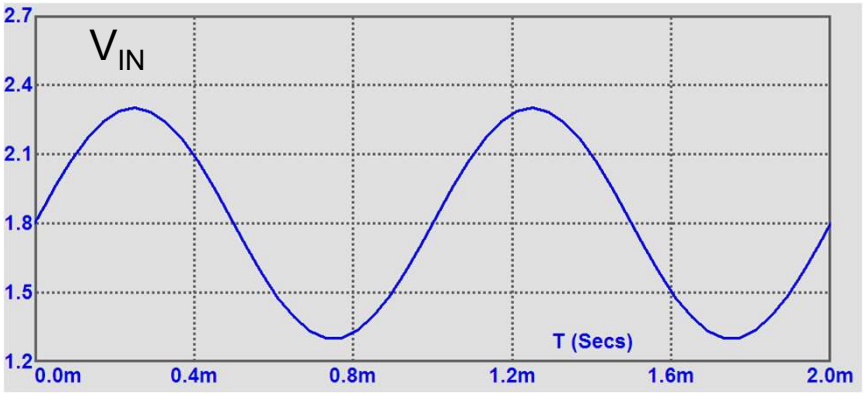



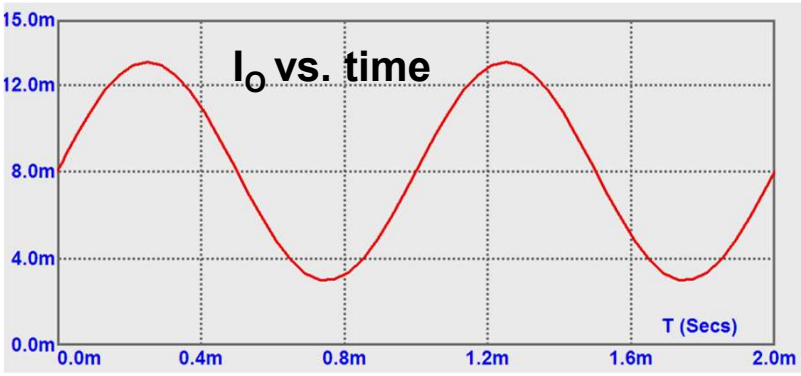

Need to choose a proper value of biasing Voltage

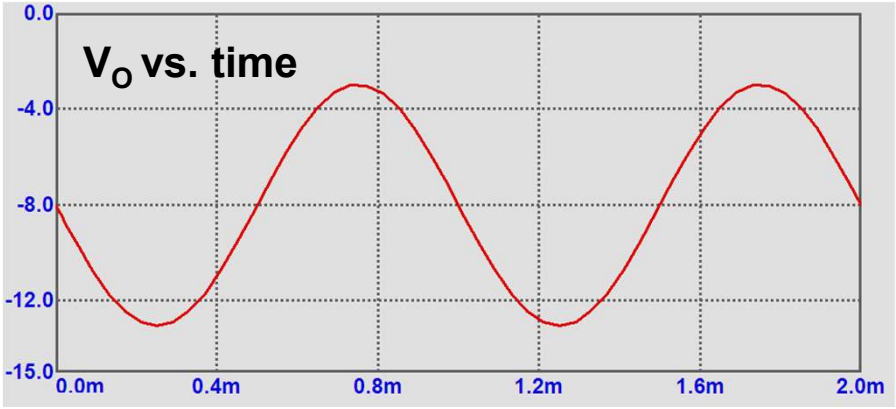
## Unnecessary Power Dissipation



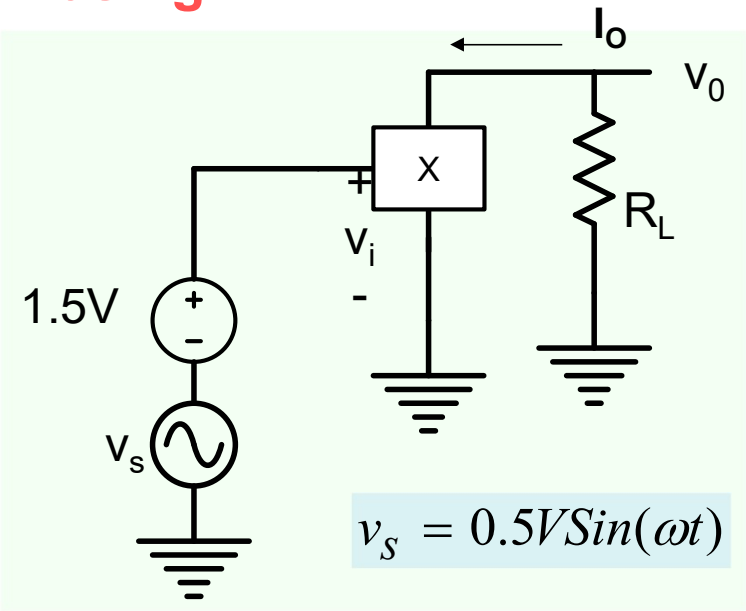



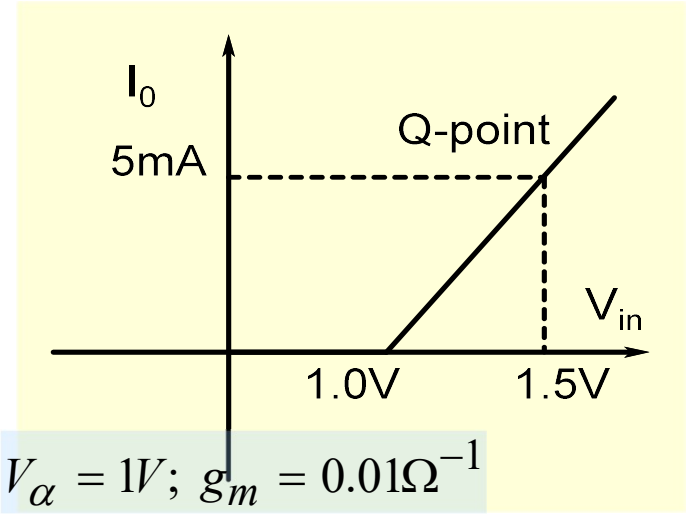



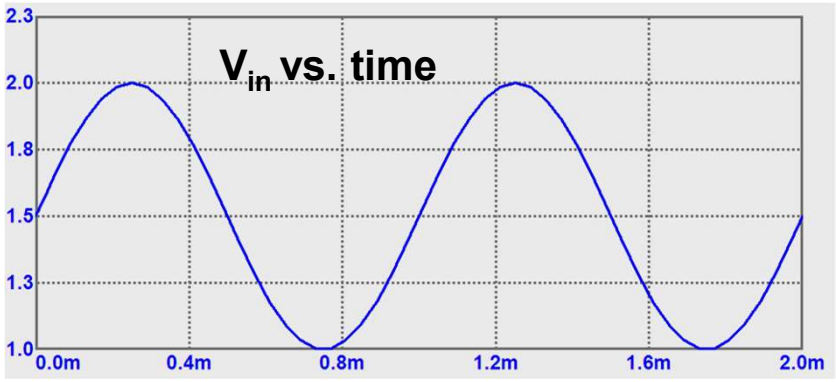
# Optimum Biasing ?

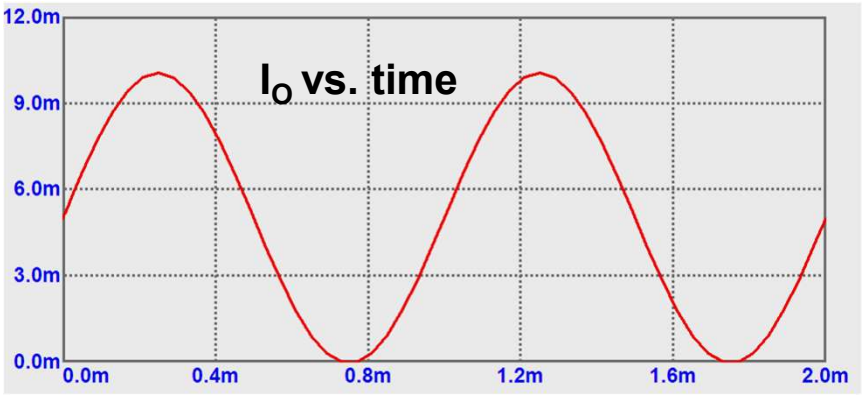


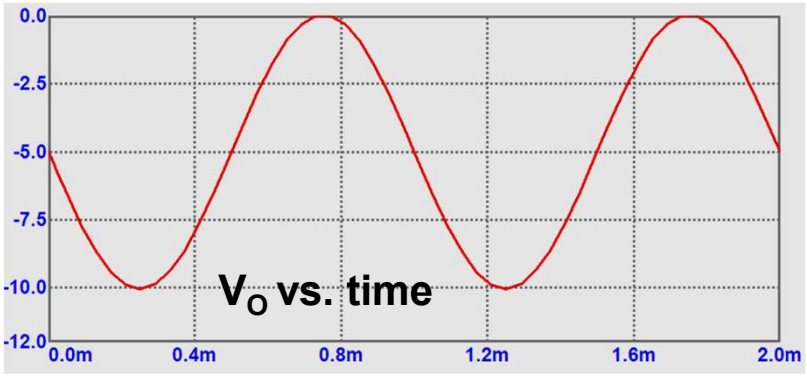

$$v_s = 0.5VSin(\omega t)$$



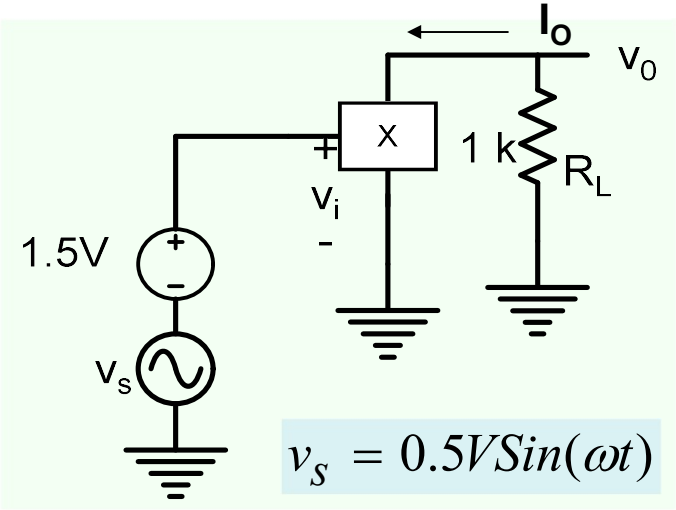

$$V_\alpha = 1V;\ g_m = 0.01\Omega^{-1}$$

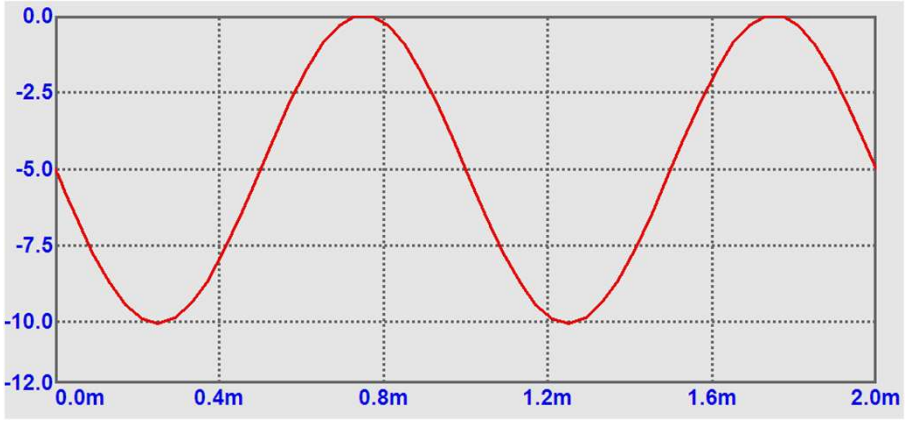


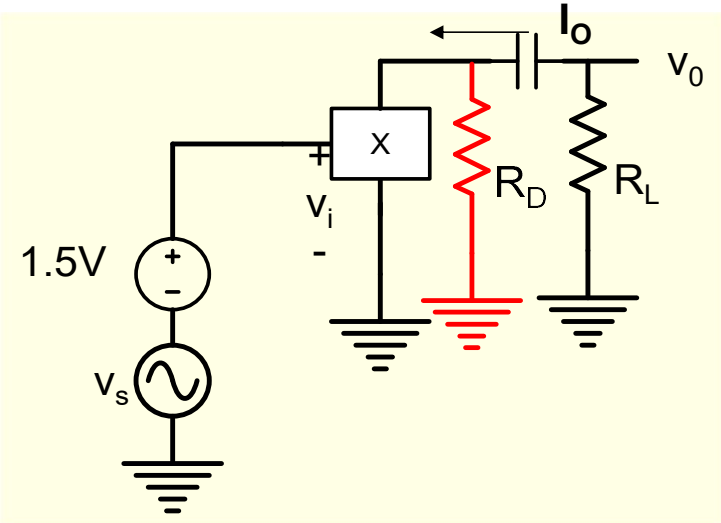



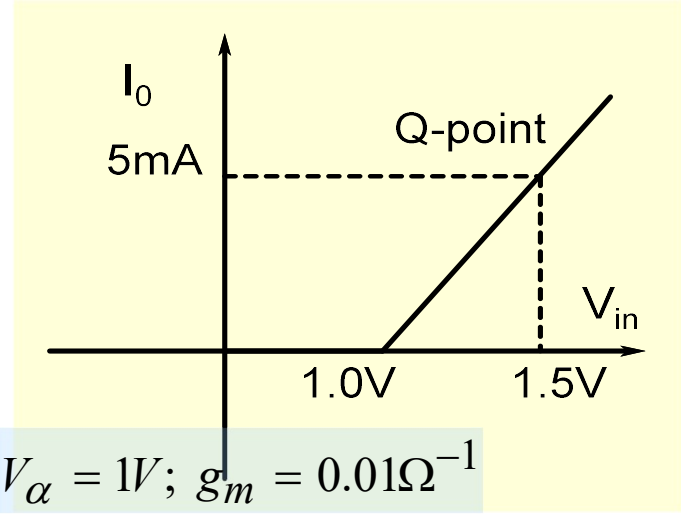



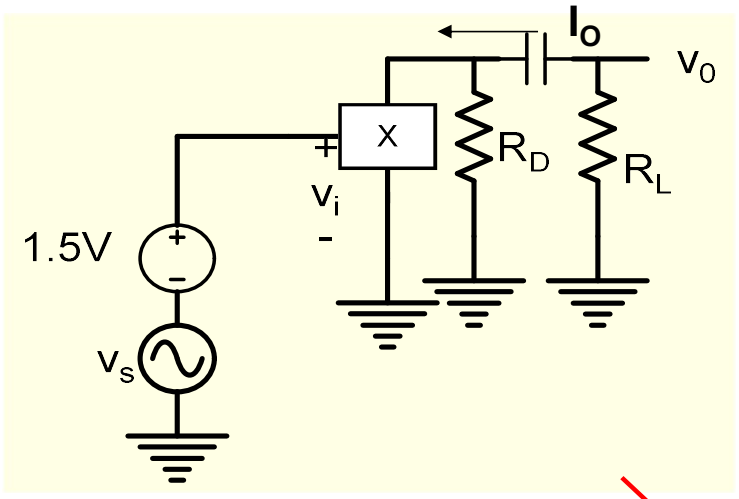
# How do we get rid of unwanted dc voltage at the output ?

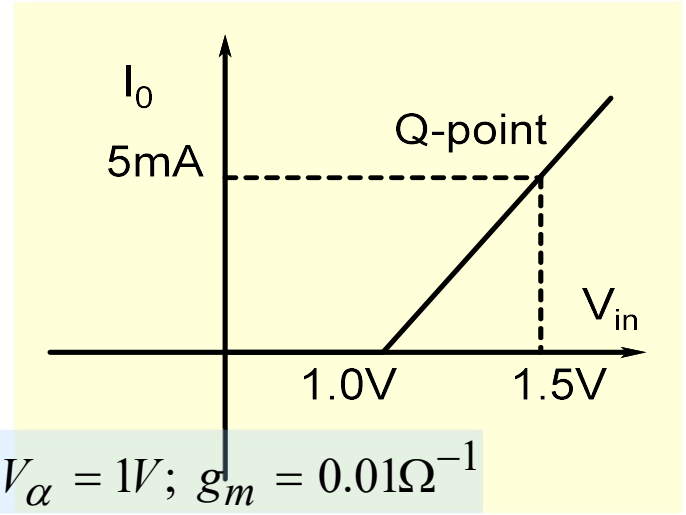


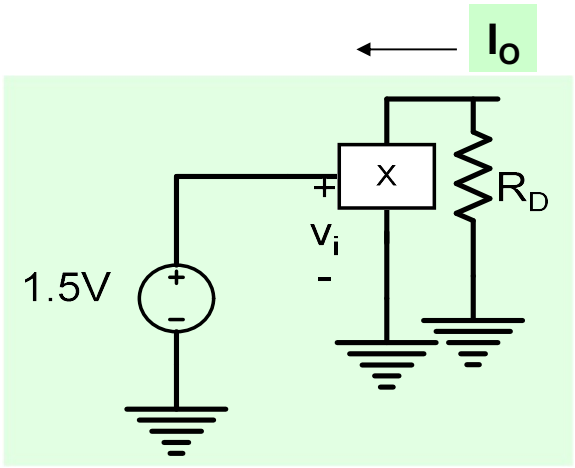


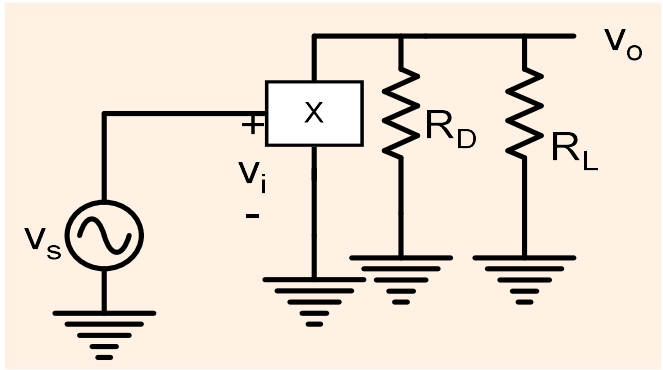




$V_\alpha = 1V;\ g_m = 0.01\Omega^{-1}$

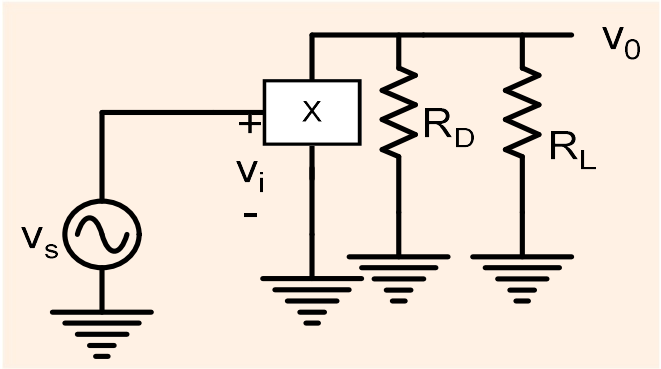
dc

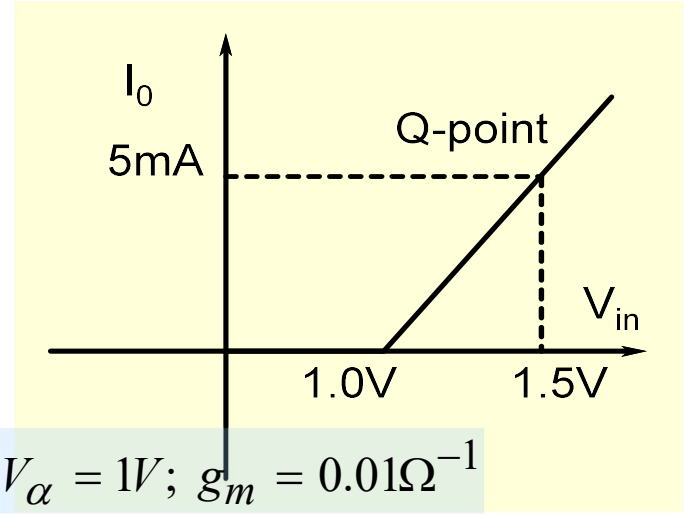
ac (signal)



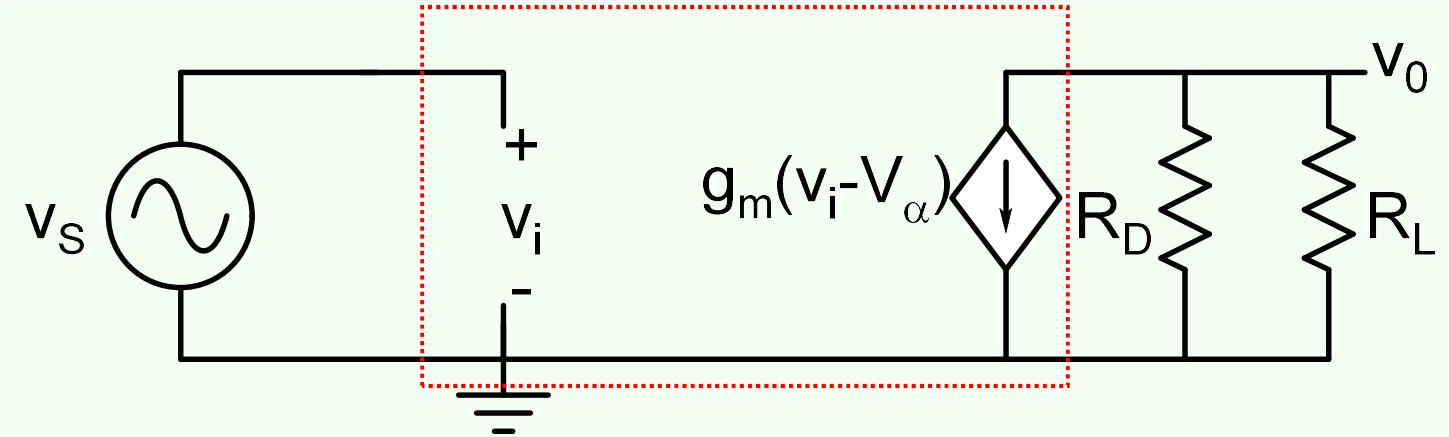

Capacitor is chosen large enough so that at the signal frequency $1/j\omega C \sim 0$.



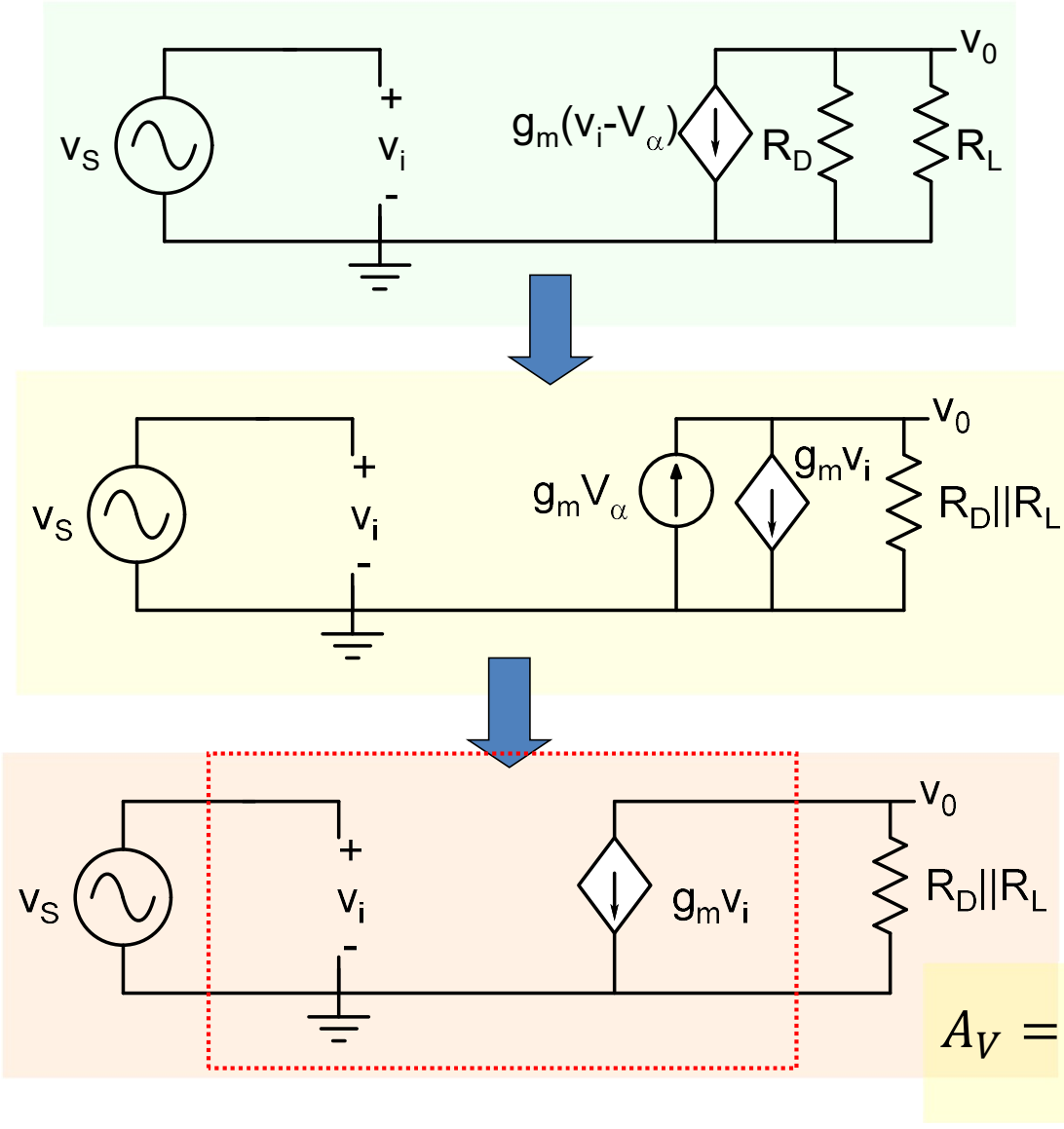




$V_\alpha = 1V;\ g_m = 0.01\Omega^{-1}$

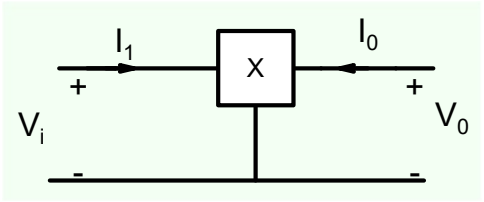
$I_o = g_m \times (V_i - V_\alpha)$ for $V_i > V_\alpha$

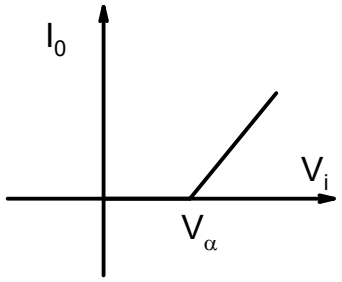


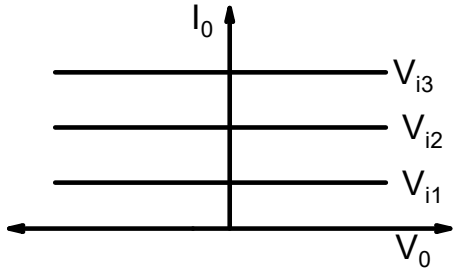
# Ac Analysis

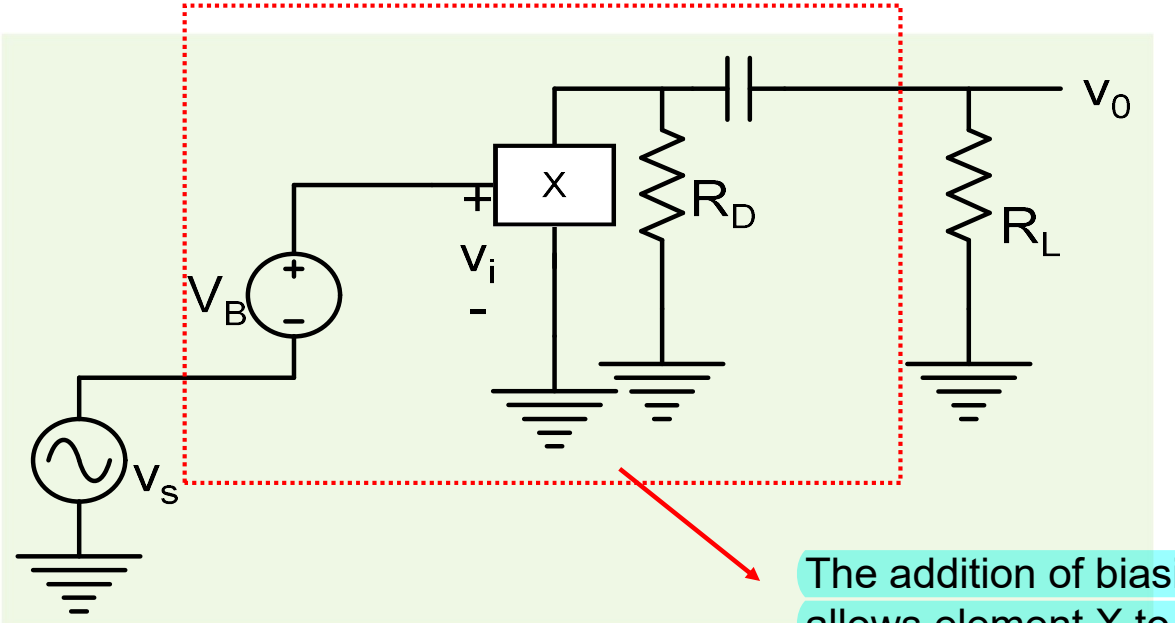


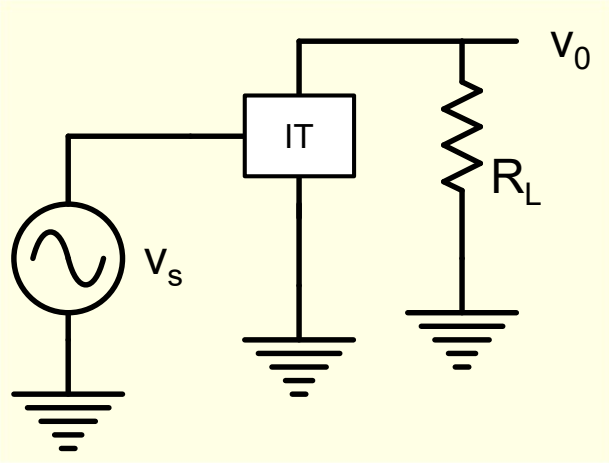

$$A_V = \frac{v_o}{v_s} = -g_m R_D \| R_L$$



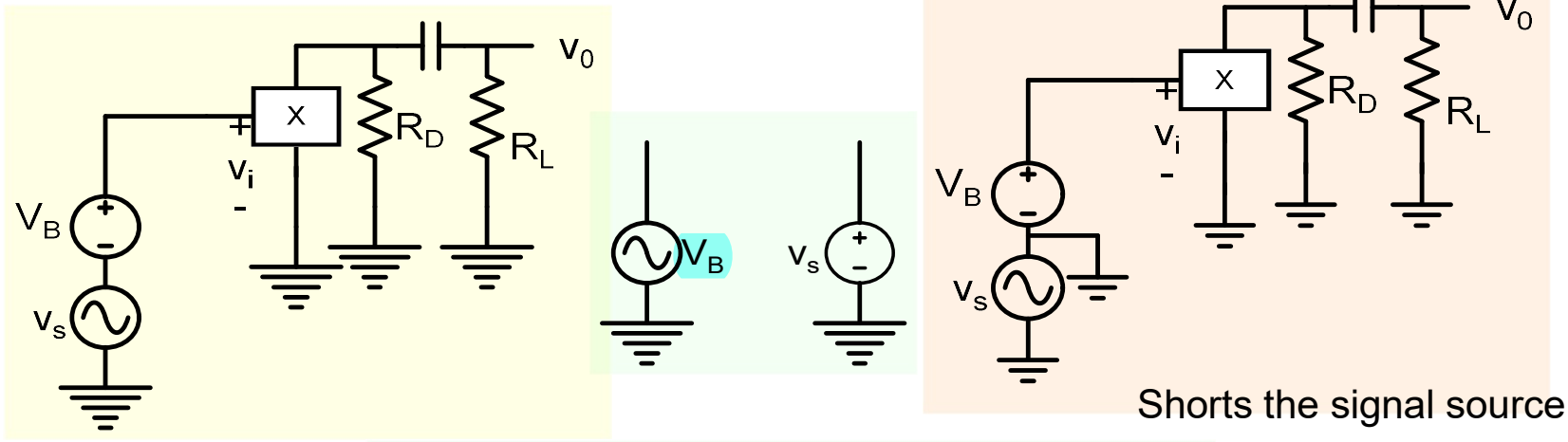



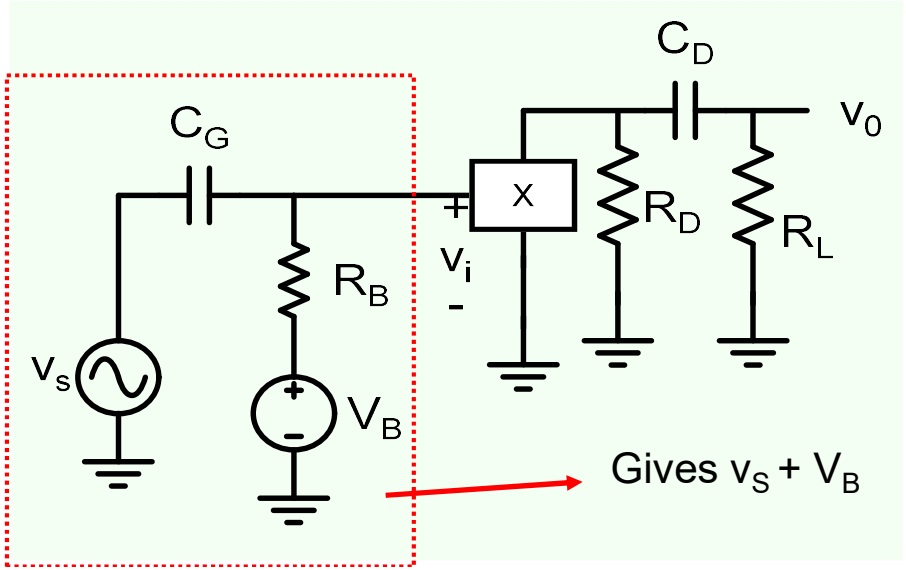



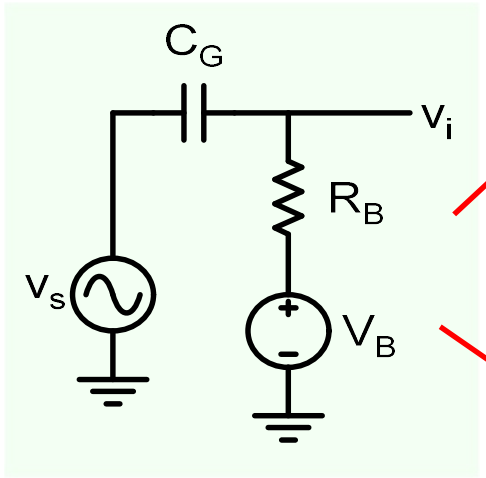

The addition of biasing network allows element X to appear as an ideal transistor to the signal source

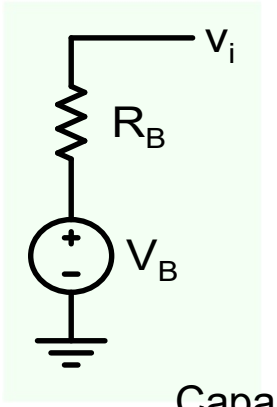
## What happens if both dc voltage source and signal source have one terminal as ground?




**Solution**

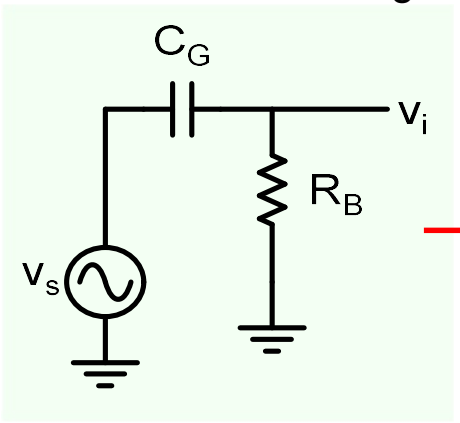


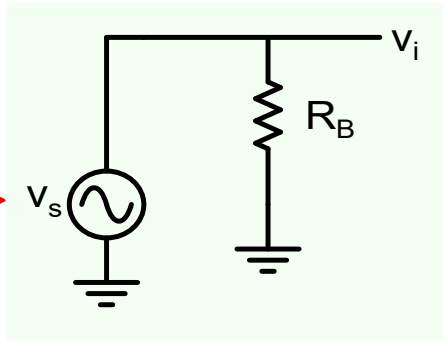



$$v_i = V_B$$

Capacitor is chosen large enough so that at the signal frequency $1/j\omega C \sim 0$.




$$v_i = v_s$$

$$v_i(total) = v_s + V_B$$

Note the role of $R_B$

# Amplifier Schematic